ANALYSIS OF COASTAL PROCESSES
FOR THE CHATHAM SOUTH COAST BETWEEN
MILL CREEK AND BUCKS CREEK

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1. INTRODUCTION

To update previous efforts associated with the analysis of coastal processes between Mill Creek and Bucks Creek located along Chatham's south coast, a limited data collection and numerical modeling effort was performed to assess ongoing changes to the area beaches and estuarine systems. Specifically, the analysis work was primarily focused on the movement of littoral sediments within the Mill Creek to Bucks Creek region. Due to the recent shoaling at the mouth of the Mill Creek/Taylors Pond and Bucks Creek estuarine systems, an understanding of longshore sediment transport processes is required to ensure effective management/stability of the inlet system. Shoaling has likely impacted tidal circulation through both entrances; therefore, an evaluation of these circulation impacts and the associated water quality impacts also was included in the evaluation. The following tasks were completed to assess local coastal processes in the vicinity of the Mill Creek and Bucks Creek entrances:

1. Bathymetry survey of the entrance regions. Two cross-channel transects were surveyed for both systems (i.e., four total transects) to determine the most constricted portions of the Mill Creek and Bucks Creek inlets.
2. Development of scenarios for the existing Massachusetts Estuaries Project models of Bucks Creek/Cockle Cove Creek Estuary and Taylors Pond to evaluate potential water quality impacts associated with the shoaled inlet systems.
3. Evaluation of local shoreline change (both recent and long-term). Two differential GPS surveys of the observed high water line were performed in 2007 to evaluate recent changes in shoreline position. These shorelines extended from the beach west of the Mill Creek entrance to the Bucks Creek entrance. Comparison of the 2007 surveyed shoreline position with historic shorelines provided needed information for the evaluation of sediment movement in this region.
4. Using the shoreline change information and the existing GENESIS model developed by Applied Coastal of this shoreline stretch, an updated estimate of local littoral transport rates has been developed. This shoreline change model provided the basis for recommendation for future sand management efforts for the Cockle Cove/Ridgevale Beach system.

2. WATER QUALITY CHANGES DUE TO INLET SHOALING

The existing hydrodynamic and water quality models for the Bucks Creek and Mill Creek estuarine systems, which bound Cockle Cove Beach, were updated to recent shoreline data and channel bathymetry. The Bucks Creek system includes the Cockle Cove Creek and Sulphur Springs sub-embayments. The Town wastewater treatment facility presently recharges treated water via filtration basins in the upper portion of the Cockle Cove Creek watershed. The Mill Creek system includes Taylors Pond, a deep kettle pond. Data collected during the May 31, 2007 survey (shown in Figures 1 and 2) of the beach were used to modify the hydrodynamic grids of these systems. Bathymetry were measured along four cross-channel transects using a survey level and rod. All the water quality model runs for this study utilized the results of the most recent MEP watershed nitrogen loading analysis (Howes, et al., 2007) performed for the Town.

Comparisons of hydrodynamic model output are presented in Figure 3 for Sulphur Springs and Figure 4 for Mill Creek. In these figures, the models modified to simulate 2007 inlet configurations are compared to the original models which simulate hydrodynamic conditions measured in 2000 (Howes *et al.*, 2007). For Bucks Creek, the 2007 inlet is wider and shallower than it was in 2000.

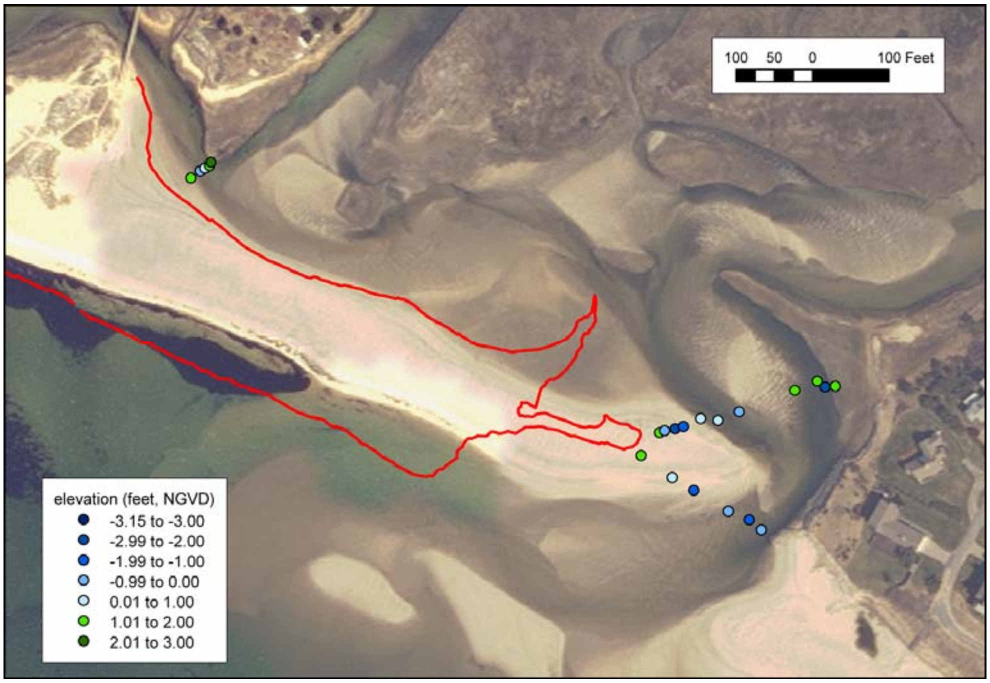

Figure 1. Plot of channel cross sections surveyed May 31, 2007 at the inlet to Bucks Creek. Survey Points and the measured GPS shoreline (solid red line) from the same day are plotted over an April 2005 Mass GIS aerial orthophoto.

Figure 2. Plot of channel cross sections surveyed May 31, 2007 at the inlet to Mill Creek and Taylors Pond. Survey Points and the measured GPS shoreline (solid red line) from the same day are plotted over an April 2005 Mass GIS aerial orthophoto.

The model tides shown in Figure 3 show that the lowest range of the tide in 2007 is higher than it was in 2000. This is due to the shallower inlet channel in 2007. This plot also shows that the high range is slightly higher and the flooding tide rises fast for the 2007 inlet compared to 2000. This effect is due to the wider inlet channel in 2007.

For Mill Creek, the model comparison presented in Figure 4 shows that the inlet for this system has become less efficient in 2007 with the growth of the Forest Beach spit across the inlet. The tide range of Taylors Pond in 2007 is reduced by 0.35 feet, or 10% of the tide range in 2000.

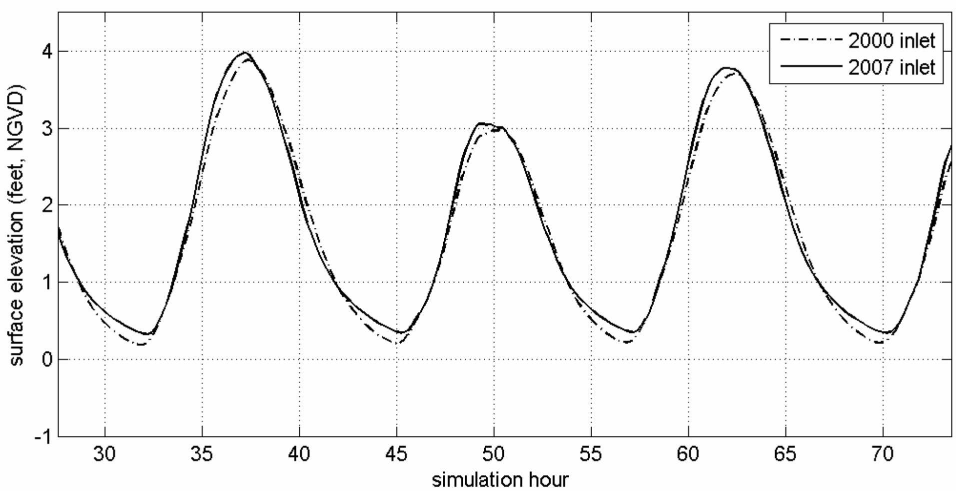

Figure 3. Comparison of modeled tides in Bucks Creek, for 2000 (dot-dashed line) and 2007(solid line) inlet configurations.

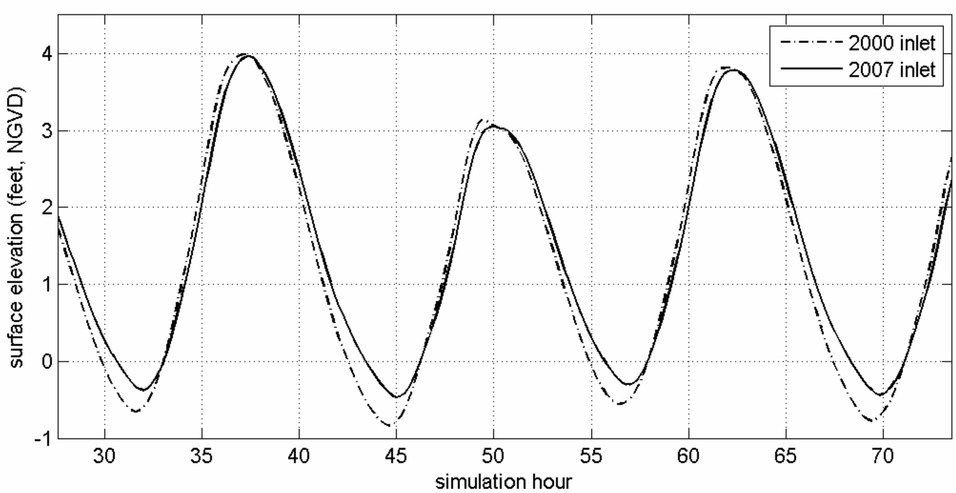

Figure 4. Comparison of modeled tides in Mill Creek, for 2000 (dot-dashed line) and 2007(solid line) inlet configurations.

In addition to the hydrodynamic model, the total nitrogen (TN) constituent transport models previously developed for these two systems (Howes *et al*., 2007) where re-run using the output of the modified hydrodynamic models. A comparison of output from these models are presented in Table 1.

The Bucks Creek model show that the 2007 inlet is slightly more hydraulically efficient than it was in 2000. Because the system flushes better, the upper portion of Cockle Cove Creek experiences a reduction in average TN concentration. However, this improvement in the upper creek results in a slight increase in TN concentrations in the remainder of the system. This is because the improved flushing of the whole estuary in 2007 transports more nitrogen to the lower portion of the system, resulting in higher average concentrations.

Table 1. Total nitrogen (TN) results for the Bucks Creek and Taylors Pond system, comparing modeled 2000 and 2007 inlet hydraulic conditions. All results were computed using the results of the most recent MEP loading analysis (Howes *et al.*, 2007).

sub-embayment	2000 inlet conditions (mg/L)	2007 inlet conditions (mg/L)	% change
Bucks Creek			
Cockle Cove Cr. – mid	1.373	1.336	-2.7%
Cockle Cove Cr. – low	0.410	0.414	1.0%
Bucks Creek	0.347	0.371	6.9%
Sulphur Springs	0.452	0.462	2.1%
Taylors Pond			
Mill Creek	0.329	0.322	-2.1%
Taylors Pond	0.455	0.473	4.0%

In Mill Creek, the hydrodynamics clearly showed that flushing is impaired by the 2007 configuration of the inlet. The TN mode results shown in Table 1 show that the reduced flushing causes an increase in TN concentrations at the head of the system (i.e., in Taylors Pond) of 4.0%. Because more nitrogen is held in Taylors Pond, there is a decrease in TN concentrations closer to the inlet of Mill Creek.

3. HISTORICAL SHORELINE CHANGE ANALYSIS

As described in the Massachusetts Estuaries Project (MEP) report regarding the Mill Creek and Bucks Creek entrances, this portion of the Chatham coast has experienced significant changes to the offshore shoal complex and the associated tidal inlet locations. More recently, attachment of the shoal system fronting Cockle Cove and Ridgevale Beaches to the mainland shoreline led to closure of the inlet that serviced Cockle Cove Creek. At the present time, both Cockle Cove Creek and Sulfur Springs share a tidal inlet at Buck's Creek. In addition to the rapidly changing shoal system associated with these beaches, the barrier beach system immediately to the west of the Mill Creek entrance has exhibited significant accretion over the past ~30 years. This accretion has resulted in the updrift (west) jetty becoming filled to entrapment, as well as the associated development of a spit across the historic thalweg of the channel.

Due to the relatively rapid changes in shoreline position and concerns regarding effective placement of nourishment material within the Cockle Cove/Ridgevale Beach system, a quantitative assessment of shoreline change was performed. The shoreline change assessment consists of two general "reaches" or shoreline segments (see Figure 5): one extending from Forrest Beach parking lot to the Mill Creek entrance and the second extending from the east end of the revetment to the west of Cockle Cove Beach parking lot to the Bucks Creek entrance. The short stretch of shoreline between the two reaches was not included in this study, since the previous study (Kelley, S.W., and J.S. Ramsey, 2000) showed that there is little shoreline change in this area.

Figure 5. Overall study area showing the two areas (Reach 1 and 2) where shoreline change analyses were performed.

The assessment west of Mill Creek is focused on the continued increase in beach width, especially in the immediate vicinity of the Mill Creek west jetty. In addition, results from oblique aerial photography and differential GPS surveys of the Mill Creek spit/shoal were evaluated to assess potential future migration of these features.

For the Cockle Cove/Ridgevale Beach system, the focus of the shoreline change analysis is on the performance of the Cockle Cove beach nourishment project placed to the west of the parking lot. Migration of the nourishment material out of the original placement template was expected; however, a quantitative assessment of nourishment performance has not previously been performed. The evaluation of the nourishment project also includes a description of sediment transport pathways, as well as potential beneficial and adverse impacts associated with the west-to-east migration of littoral sediments.

Shoreline change rates for two areas along Chatham's south coast were performed for this analysis, as shown in Figures 5 and 6. Shoreline positions from 1978, 1994, 1999, 2005 and 2007 were determined using different sources. The 1978 shoreline position was compiled from aerial surveys by the Massachusetts Office of Coastal Zone Management. The 1994 and 2005 shoreline positions were visually interpreted from color orthophotographs available from MassGIS. The 1999 and 2007 high-water shorelines were collected using a differential Global Positioning System (GPS). The location of the GPS shoreline was determined visually from morphologic features present on the beach and/or from a debris line when available.

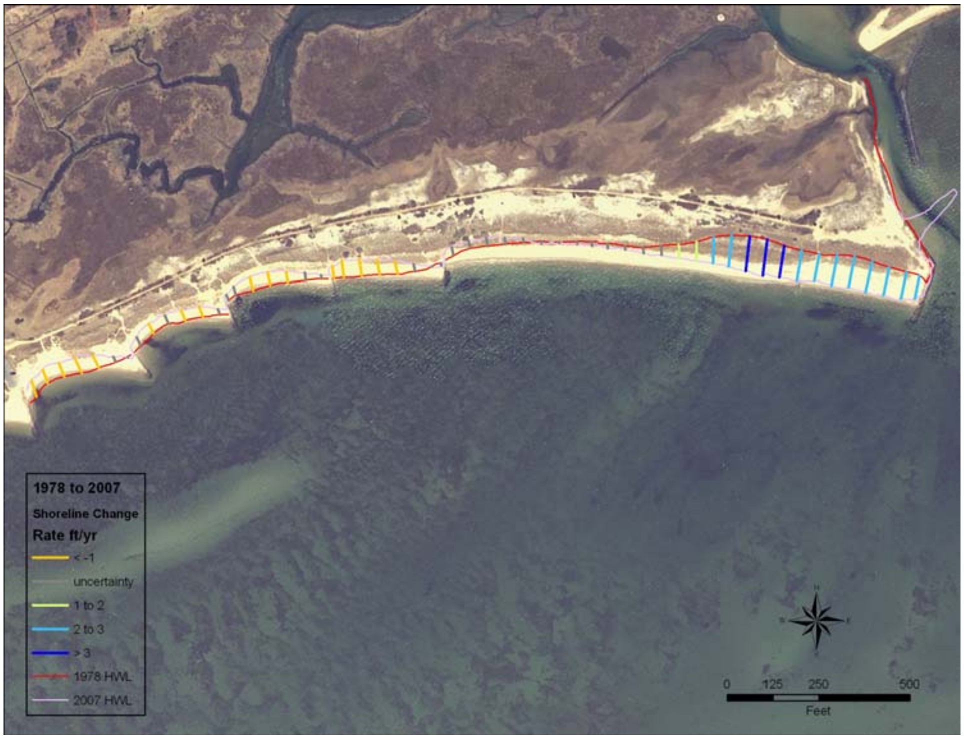

Figure 6. Historical shoreline change for Reach 1 (Forrest Beach parking lot to the Mill Creek west jetty) from 1978 to 2007. Shorelines are shown overlaid on the 2005 MassGIS aerial orthophoto of the area.

Figure 7. Historical shoreline change for Reach 1 (Forrest Beach parking lot to the Mill Creek west jetty) from 1994 to 2007. Shorelines are shown overlaid on a 2005 MassGIS aerial orthophoto of the area.

Rates of change in high-water shoreline position between 1978 and 2007 and 1994 and 2007 were evaluated 2500 feet to the west of the Mill Creek jetty (Reach 1). These two periods highlight shoreline changes as the two easternmost groin compartments of Forest Beach (adjacent to Mill Creek Inlet) filled with sand. The longer time period shows the infilling of the second-to-last compartment, while the shorter period between 1994 and 2007 shows the complete infilling of the eastern-most compartment.

Shoreline change rates were also evaluated east of Mill Creek for 3000 feet along Cockle Cove and Ridgevale Beaches between 1999 and 2007 and 2005 and 2007 (Reach 2). Since the focus of the analysis for the Cockle Cove/Ridgevale Beach system was performance of the 2003-2004 beach nourishment effort, a shorter time period was selected for shoreline change analysis.

The high-water shoreline position change rates were calculated in the Automated Shoreline Analysis Program that is run as an extension in ArcGIS (ArcASAP). This program requires a user-defined spatial interval (50 ft was used for this study) and the general shoreline orientation to determine the amount of shoreline advance or retreat for the time interval. ArcASAP performs the shoreline change calculations by casting transects normal to the earlier shoreline at each analysis point specified along the input shorelines. The data output is a table of shoreline change magnitudes and rates for each transect where shoreline change denoted with a minus sign represents retreat.

3.1 West of Mill Creek

During the 1978 to 2007 time interval, change rates ranged from 3.4 to -1.6 ft/year along the shoreline west of the Mill Creek jetty. Along the same stretch of shoreline the rates ranged from 5.8 to -2.1 ft/year during the 1994 to 2007 interval. The shoreline advanced during both time intervals up to 700 feet west of the jetty. The rest of the beach experienced mainly shoreline retreat during both time intervals. The magnitudes and rates of this retreat varied along the beach depending on proximity to one of the five groins. Figures 6 and 7 illustrate the shoreline change along Reach 1 for the time periods 1978 to 2007 and 1994 to 2007, respectively.

The series of groins between the Forrest Beach parking lot and the Mill Creek entrance have generally stabilized this stretch of beach, especially in the ~1,000 ft stretch immediately east of the parking lot. However, since 1978, the eastern ~1,000 ft of beach has exhibited significant accretion, with a maximum increase in beach width of over 100 feet during this period. In general, the increase in beach width progressed in a west-to-east fashion, where cells between existing groins filled to capacity prior to subsequent accumulation in downdrift (easterly) cells.

Since 1994, the cell between the groin closest to the Mill Creek entrance and the jetty became filled to capacity, allowing littoral sediments to migrate beyond the west jetty and into the navigation channel. This recent infilling of the compartment immediately west of the west jetty is directly linked to subsequent infilling of the seaward portion of the Mill Creek navigation channel. This blockage of the main navigation channel was a result of increased littoral transport around the tip of the west jetty.

Spit formation across the navigation channel forced boat traffic to access Mill Creek/Taylors Point from Nantucket Sound via a pathway over the dilapidated wooden section of the east jetty (Figure 8). Continued evolution of this feature showed separation of the eastern tip from the initial spit, with continued west-to-east migration of this feature. It is anticipated that this shoal feature will continue to grow and migrate in an easterly direction. Eventually the spit and downdrift shoal feature will form an inlet "bypass bar" that will facilitate more efficient sand movement from the beaches west of Mill Creek to the Cockle Cove Beach vicinity. Unfortunately, from a navigation and estuarine water quality perspective, formation of the spit and bypass bar will inhibit safe navigation through the inlet and reduce tidal flushing of the Mill Creek/ Taylors Pond estuarine system.

3.2 Cockle Cove and Ridgevale Beaches

East of Mill Creek, the 1999 to 2007 time interval experienced shoreline retreat along most of the beach with change rates ranging from 0.9 to -9.4 ft/year. From 2005 to 2007 the change rates ranged from 50 to -44 ft/year along this stretch of coast. The shoreline retreat occurred mainly at Cockle Cove Beach whereas the shoreline accreted along Ridgevale Beach and the spit at the entrance to Bucks Creek. Figures 9 and 10 illustrate the shoreline change along Reach 2 for the time periods 1999 to 2007 and 2005 to 2007, respectively.

Since completion of the approximate 28,000 cubic yard beach nourishment project placed in 2003 and 2004 (along the westernmost 1000 feet of shoreline shown in Figures 9 and 10), the feeder beach developed to the west of the Cockle Cove Beach parking lot has experienced a slightly higher than expected recession rate. By September 2007, the high water shoreline was a slightly landward of the 1999 shoreline surveyed prior to nourishment. In addition, easterly transport of littoral sediments since the nourishment project has shown a seaward expansion of Ridgevale Beach. An initial concern regarding this beach growth and changes of the shoal system at Bucks Creek entrance was that material migrating in a west-to-east direction from the nourishment project potentially was responsible for shoaling at Bucks Creek inlet.

Figure 8. Oblique aerial photograph of the Mill Creek entrance in October 2007. This photograph was taken near low tide to illustrate the extent and migration patterns associated with the sand spit and shoal system.

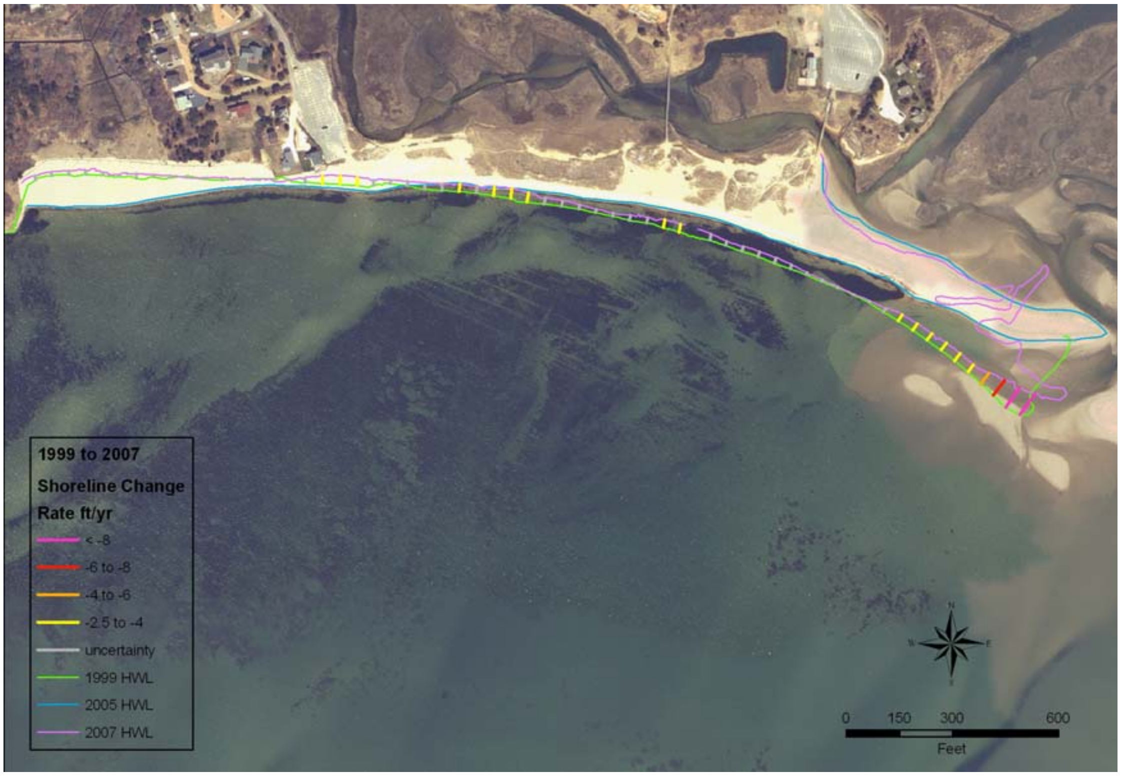

Figure 9. Historical shoreline change for Reach 2 (the east end of the revetment to the west of the Cockle Cove Beach parking lot to the Bucks Creek entrance) from 1999 to 2007.

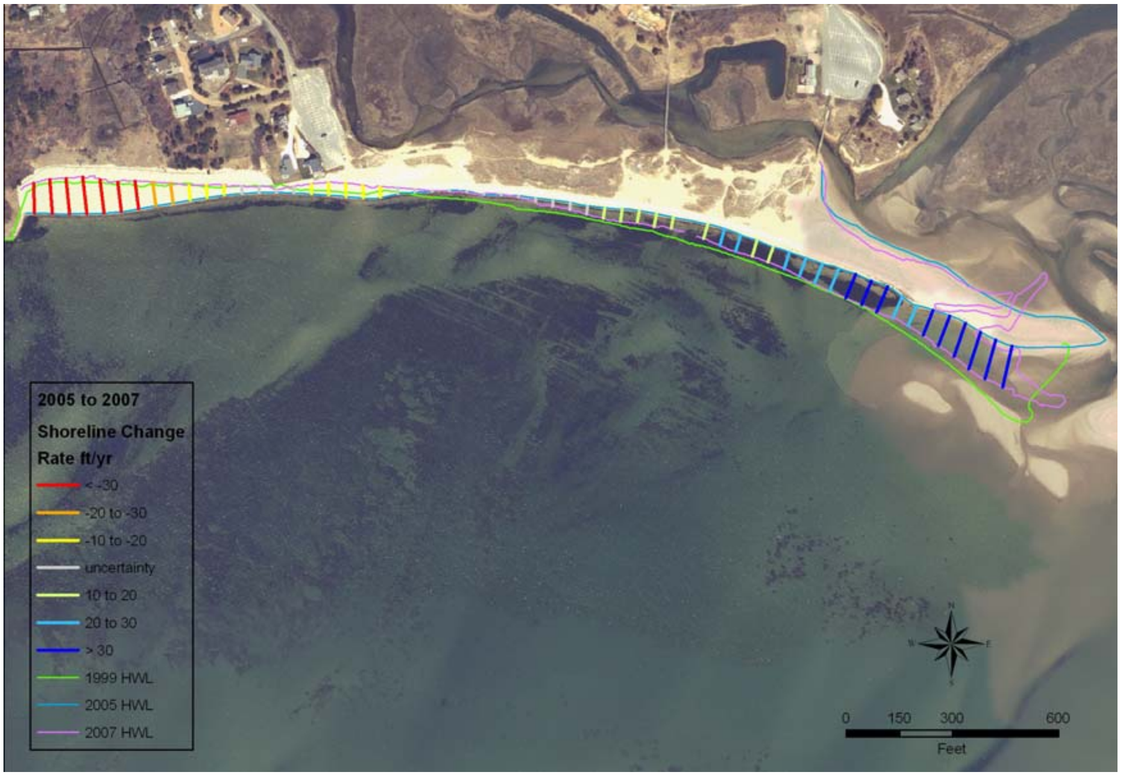

Figure 10. Historical shoreline change for Reach 2 (the east end of the revetment to the west of the Cockle Cove Beach parking lot to the Bucks Creek entrance) from 2005 to 2007.

A review of the shoreline change information indicates that the entire Ridgevale Beach system rotated seaward during the period following nourishment. However, the seaward limit of the beach in September 2007 remains landward of the 1999 position. Although there have been significant fluctuations in the position of the eastern tip of the Ridgevale Beach over the last few years, there is no indication that these changes have had an impact on tidal flushing or inlet stability. Overall, the shoreline change analysis indicates that the feeder beach is indeed partially responsible for seaward migration of the Ridgevale Beach shoreline (as planned); however, this accretion is within the bounds anticipated and remains landward of the 1999 shoreline.

3.3 Shoreline Analysis Error

All shoreline position data contain inherent errors associated with field and laboratory compilation procedures. The potential measurement and analysis uncertainty between the data sets is additive when shoreline positions are compared. Because the individual uncertainties are considered to represent standard deviations, a root-mean-square (rms) method was used to estimate the combined potential uncertainties in the data sets. The positional uncertainty estimates for each shoreline were calculated using the information in Table 2. These calculations estimated the total rms uncertainty to be ±31 ft (±1.0 ft/year) for the time interval 1978 to 2007, ±20ft (±1.5 ft/year) for 1994 to 2007, ±20ft (±2.5 ft/year) for 1999 to 2007, and ±20ft (±10 ft/year) for the 2005 to 2007 time interval.

Table 2. Estimates of Potential Error Associated with Shoreline Position Surveys.

Cartographic Errors (1978)	Map Scale 1:10,000
Inaccurate location of control points on map relative to true field location Placement of shoreline on map Line width representing shoreline Digitizer error Operator error	Up to ±10 ft ±16 ft ±10 ft ±3 ft ±3 ft
Historical Aerial Surveys (1978)	Map Scale 1:10,000
Delineating high-water shoreline position	±16 ft
Orthophotography (1994, 2005)	
Delineating high-water shoreline position Position of measured points	±10 ft ±10 ft
GPS Surveys (2007)	
Delineating high-water shoreline position Position of measured points	±3 to ±10 ft ±3 to ±10 ft

4. SHORELINE CHANGE MODELING

The shoreline change mode GENESIS was used to simulate the recent period from the completion of the 2004 Cockle Cove nourishment up to present. The model originally developed to evaluate nourishment alternatives (Kelley and Ramsey, 2000) was modified to include recent shoreline data. The GENESIS model of Cockle Cove Beach spans a 3,220 ft stretch of the Chatham south coast from the entrance of Mill Creek, east to the inlet at Bucks Creek. This reach of shoreline is modeled with 161 points, equally spaced at 20 ft intervals. The shoreline position is specified at each of the points, and is referenced to a longshore baseline as shown in Figure 11. All shoreline positions are referenced with respect to a constant baseline and vertical datum to allow for accurate comparisons of shorelines computed with GENESIS.

4.1 MODEL DEVELOPMENT

For the Cockle Cove application, the shoreline position represents the distance from a Massachusetts State Plane coordinate (2709250 ft Northing), which serves as the baseline (x-axis in Figure 11), to the mean high water line interpreted from the 1994 aerial photograph and in the field during the October 1999 survey. The origin of the GENESIS coordinate system is located at the northwest limit of the grid (1064353 E, 2709250 N).

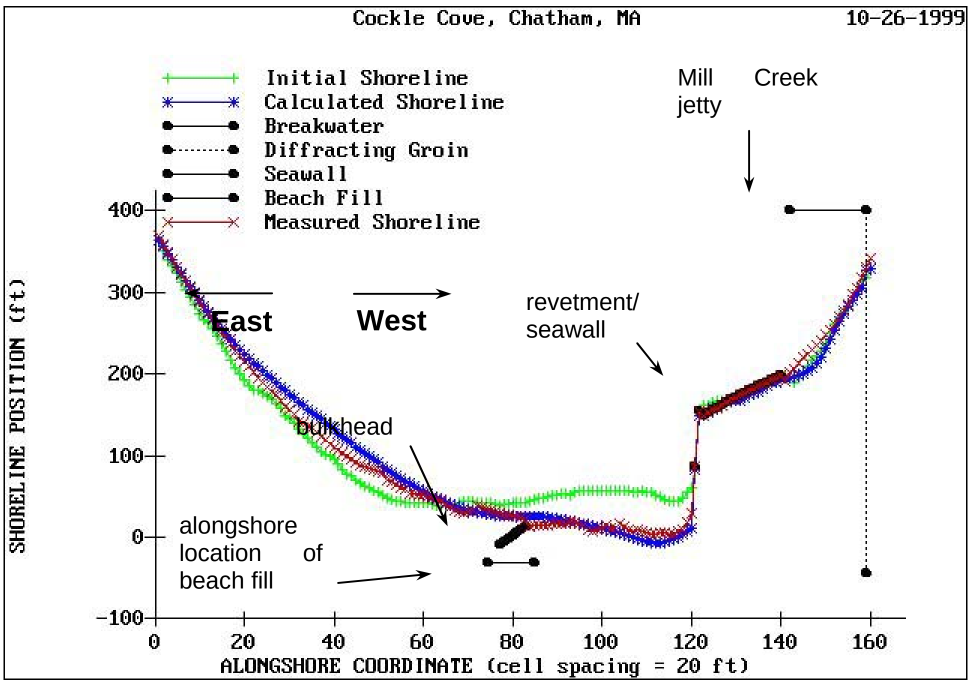

Figure 11. SMS display of GENESIS output from the original analysis of Cockle Cove Beach. Shown in the plot are model representations of structures located on the beach, as well as modeled location of recommended beach fill design. The offshore direction (south) is up in this plot.

4.1.1 Shoreline data

For proper implementation of GENESIS, at least two shorelines are required, one for input into the model for initial conditions, and a second for reference during calibration. A reasonable length of time, on the order of years, should separate the shoreline data sets in order to properly capture the long-term macro-scale effects of coastal processes in the area of concern.

The initial shoreline used in the model was measured using a geo-referenced orthophoto of Chatham, available on-line through Mass GIS. This aerial photograph was taken in April

2005. A portion of the complete orthophoto is shown in Figure 12, in the study area from Mill Creek on the west side to Bucks Creek on the east side. Position data for the second, calibration shoreline was collected on September 14, 2007, by walking the length of the beach using a differential GPS receiver. The raw GPS output of this shoreline is shown as the pale blue line included in Figure 12. Both shorelines represent the high water line as indicated by the "wrack line", which is the highest extent of flotsam recently stranded during the previous high tide near the berm crest of the beach.

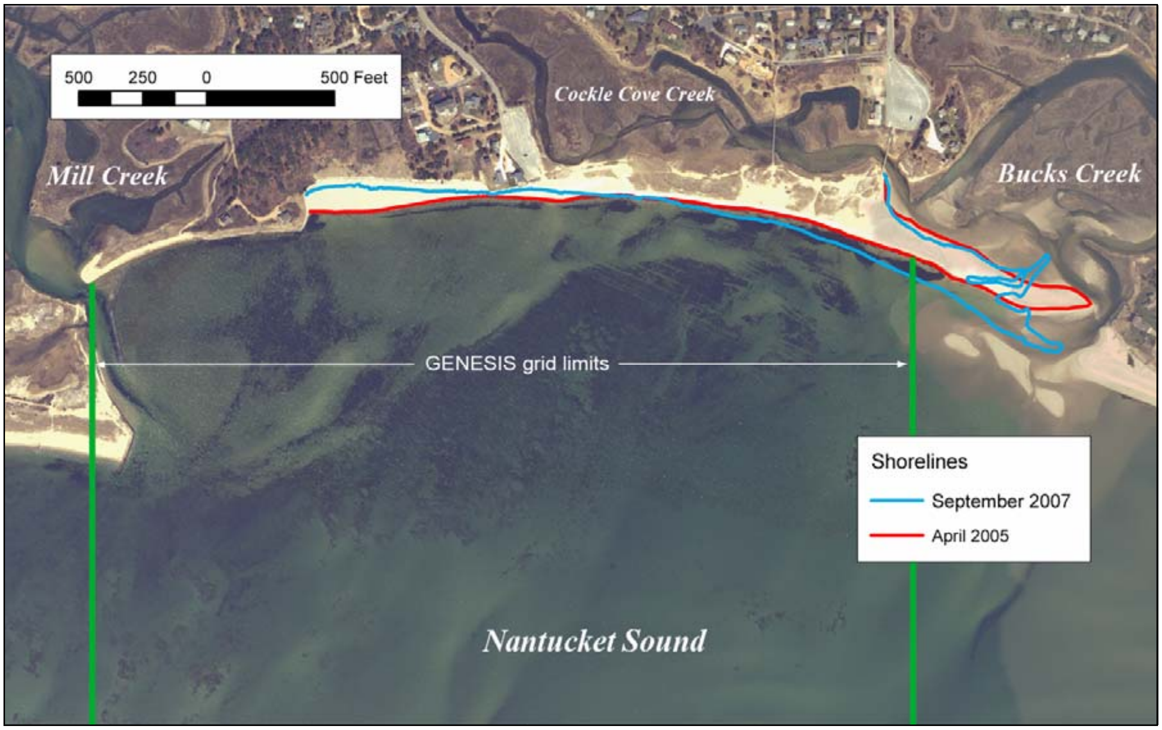

Figure 12. 2005 aerial photograph of Cockle Cove Beach, overlaid with position data for September 2007 GPS.

From a visual comparison of the aerial photograph and recent GPS data, shoreline change along this stretch of coastline is plainly evident by the movement of the Bucks Creek entrance on the eastern limit of the beach, and by the recession of the shoreline that has occurred east of the revetment indicated in Figure 11.

4.1.2 Model boundaries

Model boundaries for GENESIS were selected at the Mill Creek inlet and approximately 440 ft west of the present eastern limit of Cockle Cove Beach, at Bucks Creek. The limits of the modeled shoreline are shown in Figure 12. The inlet at Bucks Creek was not selected as the eastern boundary of the model due to the highly variable nature of this area.

The western boundary of the model was placed at the foot of the eastern jetty at the Mill Creek entrance. The model representation of this jetty is shown in Figure 11 as a composite of a diffracting groin and an offshore breakwater. This composite representation is necessary, as GENESIS cannot directly model a groin/jetty structure that is not perpendicular to the model baseline. Sand transport rates across the western model boundary are assumed to be near zero, as there is a large offset in the shorelines on each side of the inlet, and there is apparently little movement of the shoreline at this point. Therefore, the boundary was modeled as a groin with a zero permeability factor.

4.1.3 Wave data

Wave data developed for the original study (Kelley and Ramsey, 2000) were used for this study. The wave conditions used in the model were based on an evaluation of wind data recorded at the Buzzards Bay C-MAN station. Wind wave parameters were computed using the USACE computer application package ACES, and were used as input to the numerical wave refraction program REFRACT.

4.2 MODEL RESULTS

The goal of the GENESIS modeling is first to accurately predict measured shoreline change and longshore sediment transport rates, and subsequently use the model to evaluate beach nourishment alternatives for Cockle Cove. In application, this goal is achieved through a two-step process:

- Calibrate the model to reproduce historically measured shoreline change and net longshore sediment transport rates in the project vicinity.
- Use the calibrated model to simulate future shoreline change for various beach protection alternatives.

Adherence to this process ensures that the model provides accurate predictions of shoreline change for the study area of interest, subject to the limitations imposed by the model and available data. The calibration process reveals the model's ability to predict shoreline change. This allows for project-specific interpretations of model results for coastal erosion prevention alternatives. For example, if observations during the calibration process suggest that the model over-predicts beach erosion for a certain stretch of shoreline, exaggerated erosion can be expected in the same area for simulations of beach protection alternatives as well. Experience with GENESIS suggests the model can predict erosion and longshore sediment transport reasonably well; yet, areas of beach accretion tend to be exaggerated. Engineers at the USACE Coastal Engineering Research Center who developed the model have confirmed this observation.

4.2.1 Calibration

GENESIS is developed to accurately simulate measured shoreline change over a certain period of time in the *calibration* process. A number of variables (calibration coefficients) input to the model may be adjusted to ensure that model predictions closely resemble field measurements. It is essential to ascertain that GENESIS reasonably reproduces natural coastal processes before it is employed to investigate beach nourishment alternatives. Understanding the merits and weaknesses of GENESIS in reproducing shoreline change at Cockle Cove is critical for determining how to employ the model for investigating future beach nourishment scenarios.

The two-year period from April 2005 to September 2007 was selected as the model calibration interval, to determine how the 2004 nourishment has been dispersed along Cockle Cove Beach. Model results are compared to measured shoreline change data in Figure 13. Computed model error, presented also in this plot, shows that the model performance is best along the western Cockle Cove Beach shoreline, between stations 12+00 and 24+00 of the model grid. The model is less skillful between stations 5+00 and 12+00, with maximum computed errors of 39 ft (16.1 ft/yr). For GENESIS shoreline modeling, this is an acceptable level of error (Gravens and Kraus, 1991). This model error may be due to coastal processes that are not included in the GENESIS code, primarily the cross shore movement of sand.

4.2.2 Sediment Transport Along Cockle Cove Beach

Beach erosion is directly related to the amount of sediment that waves transport along the coast. As discussed above, calculation of sediment transport is conservative in GENESIS, where sediment eroded from a shoreline is offset by accretion at another area or compensated for at the model boundaries. From Figure 12, the area of greatest shoreline erosion has been along the shoreline reach which was nourished in 2004. The area of greatest accretion has been along the shoreline of the western barrier spit of Bucks Creek. Figure 13 indicates that the measured two-year shoreline change ranges from a maximum erosion of 100 feet at the west end of the nourishment template, and a maximum accretion of 60 feet at the eastern boundary of the grid.

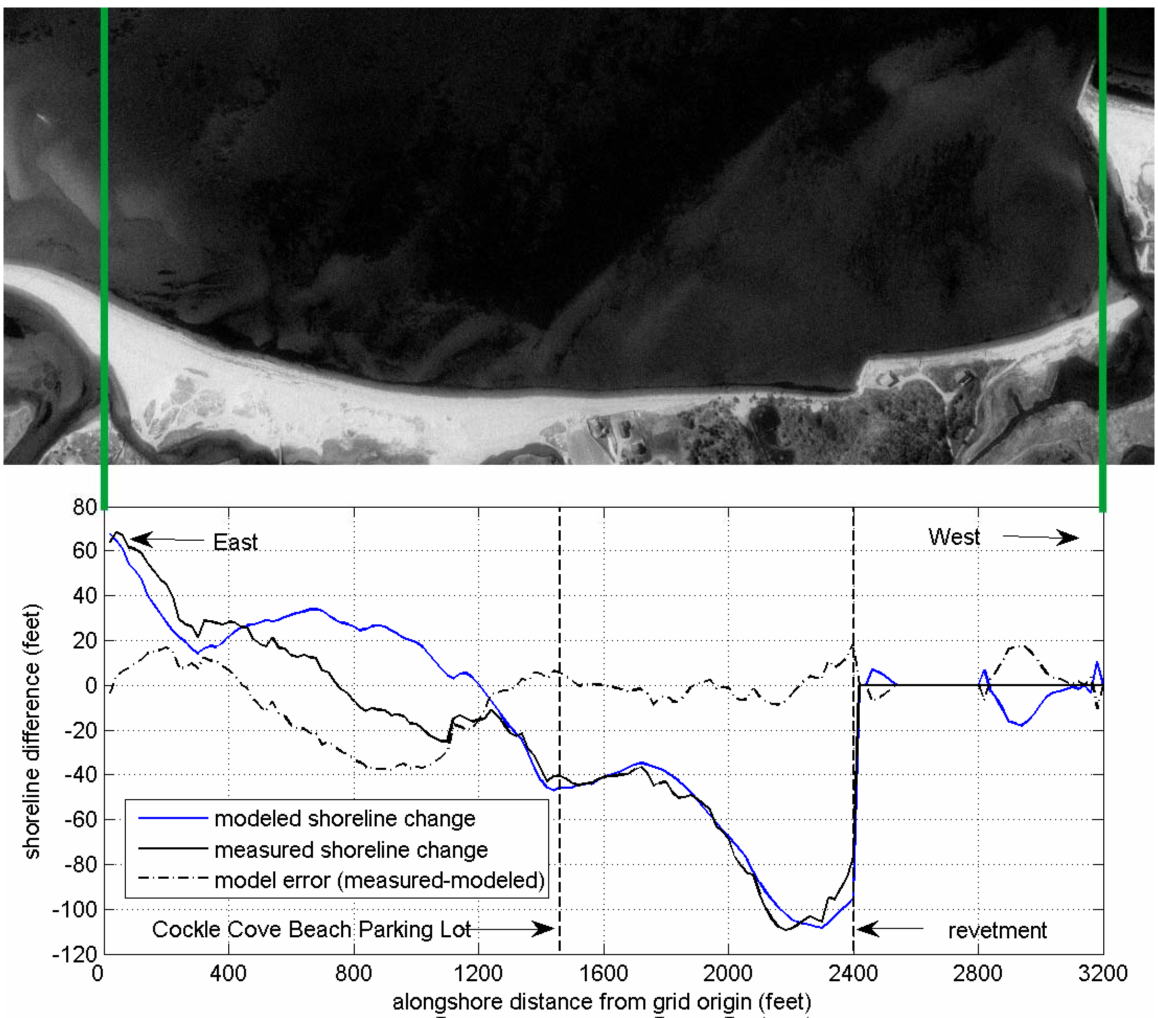

Figure 13. Aerial photo of Cockle Cove Beach shown with a plot of shoreline change from 2005 to 2007, for both measured and modeled shorelines. Difference between measured and modeled 2007 shoreline is also plotted. Solid green lines indicate the GENESIS model limits, and dashed lines indicate positions of features along the beach relative to the model grid origin.

As was observed on the original study (Kelley and Ramsey , 2000), there was no clear trend to the shoreline change between the revetment and the Mill Creek jetty. Slight erosion is indicated by the recent shoreline change data. Although much of the dune backing this region appears to be well-vegetated and stable, the low-lying dune feature shows evidence of overwash during storm events. Due to the limited shoreline change in this area and the natural sheltering of this shoreline by the Mill Creek jetties, the region west of the revetment can be considered its own littoral cell.

For the purpose of this analysis, the GENESIS modeling was used to evaluate shoreline change and sediment transport rates between Mill Creek and Bucks Creek. The region directly influenced by the cyclical spit growth/breaching process adjacent to Bucks Creek was not evaluated. Results of the GENESIS modeling effort are shown in Figures 13 and 14. Generally, the erosion/accretion trends indicated by the measured shoreline change are depicted well (Figure 13). GENESIS model results illustrate good agreement in the shoreline location of erosion-to-accretion transitions, and the shoreline change magnitude over the five-year period. The mean error in predicted shoreline change was 4.4 ft or approximately 4% of the maximum observed shoreline change. Maximum error in predicted shoreline change was 38 ft (Figure 13).

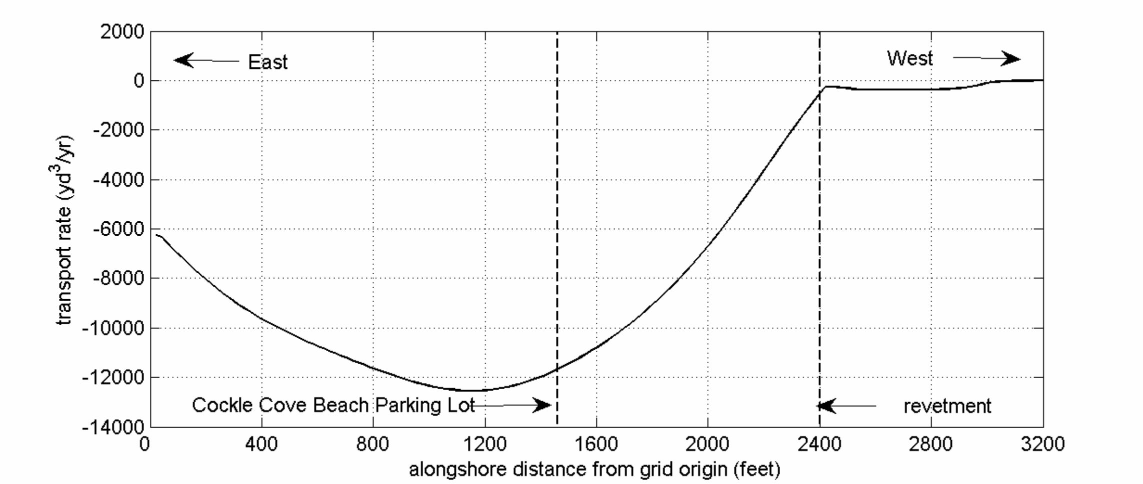

Figure 14. Net sand transport rates (cubic yard / year) along Cockle Cove Beach computed using the GENESIS model of the shoreline, for the 2005 to 2007 simulation period. Negative rates denote net sand movement to the east. Dashed lines indicate positions of features shown in Figure 11.

Due to the simplifications inherent in the model and input conditions, the magnitude of erosion and accretion were slightly over-predicted by GENESIS. However, the overall agreement in predicting areas of erosion/accretion, as well as the magnitude of shoreline change, provides confidence that GENESIS can be used to evaluate the 2004 nourishment performance. Shoreline change trends are modeled most accurately along the shoreline extent that was nourished (1400 feet to 2400 feet from the east grid origin).

Figure 14 indicates calculated annual longshore sediment transport rates along the modeled shoreline. Sediment transport rates range from negligible transport adjacent to Mill Creek inlet to approximately 12,500 cubic yards per year at a point 1200 feet from the east boundary of the model. The mean east-directed transport rate was calculated to be 9,200 cubic yards annually, for the shoreline between the model east boundary and the revetment.

The shoreline change and sediment transport rates computed with the updated model of the shoreline are greater than what was determined in the previous study of this shoreline. The maximum transport rate in the prior analysis was computed to be 6,300 yd^3/yr, which is approximately half of the maximum from the updated model. A cause for this difference is due to the wave climate of the time between the completion of the nourishment in 2004 and present. Figure 15 shows a comparison between the wind record for the entire span of available data (from 1985 through 2007) and the data from the time between 2005 and 2007 only. This comparison shows that the most recent two years had a greater percent occurrence of winds, and therefore waves, from the WSW through SSW sectors. For all winds blowing over open fetches in Nantucket Sound to Cockle Cove Beach, there was an increase of 4% in the percent occurrence between 2005 and 2007 over the long term average. More wave energy from the southwest would, therefore, cause greater transport to the east along the shoreline.

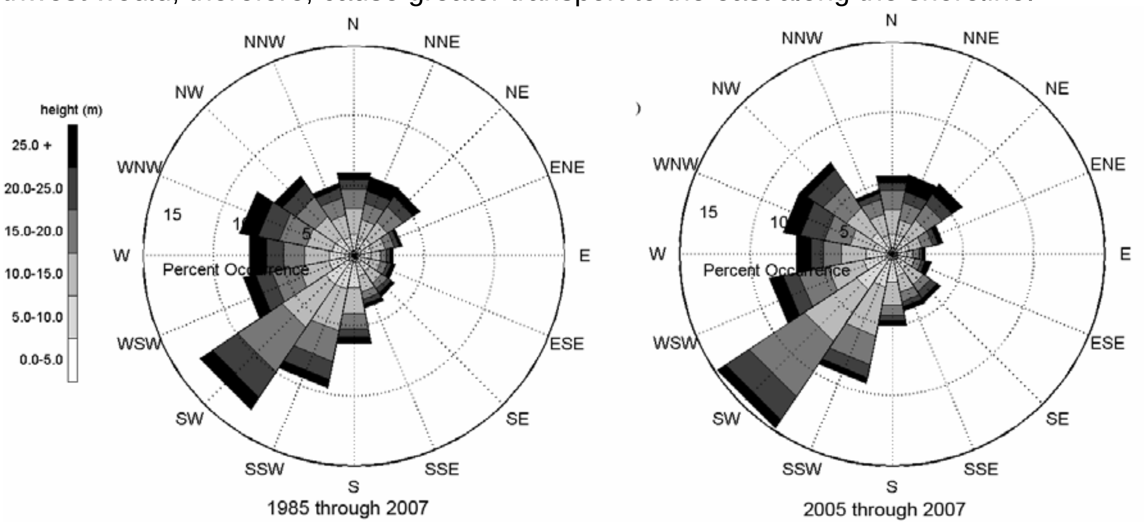

Figure 15. Comparison of winds from the Buzzards Bay C-MAN station. The rose plot to the left shows a summary of the entire data record spanning from August 1985 through May 2007. The plot to the right shows a sub-set of the data between April 2005 and May 2007. In these plots, direction indicates from where wind was blowing. Grey tone segments indicate magnitude of wind speeds. Radial length of each segment indicates percent occurrence over the total duration of the data record.

As an independent check of the GENESIS model results, an estimate of beach volume change was compared with computed annual longshore transport rates adjacent to Bucks Creek inlet. The results of this analysis are shown in Table 3. First, the transport rate calculated at the eastern boundary of the GENESIS model (the “pinned” shoreline boundary) was 6,200 cubic yards per year to the east.

Table 3. Comparison of sand transport rate at eastern limit of GENESIS grid to rates estimated by measured profile changes and by volume of added sand in Bucks Creek spit (annualized over 2 years)

Method used to determine rate	Transport rate (cu yd / yr)
transport rate at east boundary of GENESIS grid	6,200
estimated volume of added spit growth at Bucks Creek between 2005 and 2007	4,600

Alternately, the transport rate at the shoreline position corresponding to the model east boundary was computed using the measured area change multiplied by the elevation difference between the beach berm height and the depth of closure (11 ft, estimated based upon the average wave climate). The area coverage of the Bucks Creek spit was determined using the 2005 aerial orthophoto and the September 2007 GPS survey data. The difference in area between these two periods was calculated and divided by the intervening time in order to determine the annualized transport rate presented in Table 3. This rate does not account for volumes contained in the ebb shoal of Bucks Creek, and is a possible source of error between the modeled and estimated transport rates.

The comparison of the transport rates computed using these two methods show that the GENESIS model results are a realistic approximation of the real transport rate. The rate determined by the area calculations is expected to be smaller than that determined by the GENESIS model since the area calculation does not account for bypassing of sand from Ridgevale beach to Hardings Beach via the ebb shoal of Bucks Creek.

4.3 Error Associated With Genesis Predictions

The ability of GENESIS to simulate measured trends of beach erosion and accretion, as well as historically documented longshore sediment transport rates is valuable. However, referring to Figure 13, the amount of error associated with the predictions for exact shoreline change distance can be significant. The sources of this error are numerous, consisting of the limitations of GENESIS, limitations of the input data, and conditions specific to the Cockle Cove shoreline. The following are some specific sources of error for the Cockle Cove application:

- Nearshore bathymetric contours are not straight and parallel as assumed by the GENESIS shoreline change model, and the cross-shore profile does not fit the simplified approximation used in the model (e.g., significant tidal flats exist along a portion of the shoreline).

- The GENESIS application was limited to a single five-year time period, due to the limited amount of regional shoreline data.

- Aerial photographs indicate that there potentially is sand by-passing associated with Mill Creek jetties. GENESIS does not account for this transport mechanism.

- Offshore wave conditions were generated using simplified U.S. Army Corps of Engineers equations from wind data collected in Buzzards Bay. The wave conditions proved to be appropriate for the GENESIS modeling effort; however, this simplistic approach likely introduces some level of error.

- GENESIS is not capable of evaluating sediment transport associated with nearshore shoals in the vicinity of inlets.

Despite the possible sources of error and limitations of the model, GENESIS was able to simulate measured trends of erosion/accretion within ± 40 ft over the 2-year calibration period. In addition, independent methods for evaluating longshore sediment transport rates in the vicinity of Bucks Creek inlet indicated that GENESIS transport calculations were within approximately 1,600 cubic yards per year of measured estimates.

5. SUMMARY OF OBSERVATIONS

Updates to the various numerical models utilized to assess coastal and estuarine processes between Mill Creek and Bucks Creek were performed to assess changes resulting from the recent observed shoaling at the Mill Creek, as well as the influence of the 2003/2004 beach nourishment project placed at the west end of Cockle Cove Beach. The model updates were aimed at providing quantitative information needed for future management of Chatham's south coast. The following summarizes the findings of the study relative to coastal and estuarine processes:

- The increased shoaling at the Mill Creek entrance has a demonstrable negative impact on both tidal flushing and water quality conditions (total nitrogen concentrations) in Taylors Pond. Overall, the shoaling has created an approximate 10% reduction in tide range and a 4% increase in total nitrogen concentrations within Taylors Pond.

- Although recent visual observations indicate increased shoaling at the Bucks Creek entrance, the survey performed in May 2007 shows that the inlet throat is actually larger than the modeled 2000 inlet conditions. Aerial photographic records support this general trend of inlet widening, where the 2000 photograph exhibits the narrowest channel servicing the Bucks Creek system.

- Water quality modeling for the Bucks Creek/Cockle Cove Creek system indicate that the wider inlet improves tidal flushing within this system; however, this increased tidal exchange causes a slight increase in nitrogen concentrations in other areas of the estuarine system. A significant reduction in total nitrogen concentration in upper Cockle Cove Creek occurs as a result of the widened inlet. Slightly higher nitrogen concentrations in the Bucks Creek and Sulphur Springs areas of the estuary, where maximum computed nitrogen level increases are about 0.02 mg/L, based on the improved circulation conditions surveyed in 2007.

- The shoreline change analysis indicated that recent infilling (accretion) of the beach to the west of the Mill Creek jetty is the likely cause of the shoal formation in the Mill Creek entrance. Continued evolution of shoal feature showed separation of the eastern tip from the initial spit, with continued west-to-east migration. It is anticipated that this shoal feature will continue to grow and migrate in an easterly direction. Eventually the spit and downdrift shoal feature will form an inlet "bypass bar" that will facilitate more efficient sand movement from the beaches west of Mill Creek to the Cockle Cove Beach vicinity. Unfortunately, from a navigation and estuarine water quality perspective, formation of the spit and bypass bar will potentially further inhibit safe navigation through the inlet and reduce tidal flushing of the Mill Creek/ Taylors Pond estuarine system.

- Since completion of the approximate 28,000 cubic yard beach nourishment project placed in 2003 and 2004, the feeder beach developed to the west of the Cockle Cove Beach parking lot has experienced a slightly higher than expected recession rate. A review of the shoreline change information indicates that the entire Ridgevale Beach system rotated seaward during the period following nourishment. However, the seaward limit of the beach in September 2007 remains landward of the 1999 position. Although there have been significant fluctuations in the position of the eastern tip of the Ridgevale Beach over the last few years, there is no indication that these changes have had an adverse impact on inlet stability or hydrodynamics. Overall, the shoreline change analysis indicates that the feeder beach is indeed partially responsible for seaward migration of the Ridgevale Beach shoreline (as planned); however, this accretion is within the bounds anticipated and remains landward of the 1999 shoreline.

- The shoreline change model indicated that the annual east-directed sediment transport rate was about 9,200 cubic yards per year between 2005 and 2007. This is slightly higher than the rate predicted during the 2000 modeling effort; however, this increase is likely a result of a greater occurrence of southwest winds during this period, as well as the addition of readily available sediment in the form of the beach nourishment project.

- Overall, the shoreline change model indicated that the nourishment was responsible for reestablishing the 1999 shoreline position. There is no evidence that additional infilling of the Bucks Creek system has resulted from the nourishment effort.

6. CONCLUSIONS

To maintain the "*status quo*" for the Cockle Cove/Ridgevale Beach system, between 6,000 and 9,000 cubic yards of beach nourishment material are needed on an annual basis. A large influx of nourishment material (i.e., of the order 100,000 cubic yards or greater) could potentially have a detrimental impact on the Bucks Creek stability; therefore, we recommend smaller scale nourishment projects that place approximately 3-to-4 years of littoral sediments to the system. The placement location at the east end of Cockle Cove Beach is ideal, since it allows "natural" migration of sediment to the Ridgevale Beach system.

Placement of nourishment material directly on Ridgevale Beach in the form of a dune may reduce overtopping frequency. However, influence of this placement option on endangered species habitat needs to be considered as part of a beach nourishment alternatives evaluation.

Possible sediment sources for future nourishment efforts include the recent spit formed across the Mill Creek entrance, the shoals associated with this spit, and the updrift beach area to the west of Mill Creek entrance. Future analyses should evaluate these sand sources, as well as potential environmental regulatory issues regarding dredging and placement of this material. The modeling analysis concluded that the shoal/spit formation at the Mill Creek entrance is having a detrimental impact to water quality within Taylors Pond. Therefore, dredging of this feature, as well as potential removal of a portion of the updrift beach that has filled the west jetty to entrapment, likely would provide the volume of nourishment material required for the Cockle Cove/Ridgevale Beach system and eliminate estuarine water quality concerns created by the recent shoaling.

As part of any future effort to maintain the inlet of Mill Creek, it would be possible to remove the dilapidated wood sections of either jetty (Figure 8). Their removal likely would not cause any detrimental effects to system flushing, and would benefit navigation.

7.0 REFERENCES

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